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Microstructure of Selected Mortars Undergoing Long-Term Influence of External Environment

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Abstract

A facial wall is defined as an element used outside or inside which should have an attractive look. It is built from attractive wall elements using standard way of execution and joints filled with mortar appropriate for this type of wall element. From the point of view of durability, the mortar is a wall element which not only binds bricks but also takes part in humidity transport. It is associated with mortar microstructure which in comparison to clinker is characterized with high percentage of pores causing capillary flow and wall drying abilities. Mortars belong to the group of chemically active materials for which both internal as external factors are essential. The reason for internal corrosion are mortar components (binder, sand, water, additions). External corrosion includes all cases where mortar is threatened with external factors (CO_2 gas, acid rain, temperature changes exceeding zero point, solution of soluble mineral salts originating from surrounding elements). The factors mentioned essentially influence mortar microstructure changes. This process is distributed in time. This work concerns the analysis of changes in quantity and distribution of pores resulting from many years of functioning of mortar in facial wall threatened with external factors. The researches were performed on a field test station localized in area of the University of Science and Technology in Bydgoszcz (Poland). Three facial walls with different mortars were chosen: Portland cement based mortar CEM I, Portland cement based mortar CEM I with plasticizer and cement-lime mortar. During construction of walls, standard beams were formed from mortars in order to perform basic tests and microstructure tests after 28 days of hardening.

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During the subsequent years of wall functioning there were noticed appearances of efflorescence of various range and intensity. The information gathered allowed to define the area of highest efflorescence intensity. After ten years, for each wall, from selected place mortar samples were taken to examine microstructure with mercury porosimetry method. The results served to evaluate changes of meso and macro pores in mortars due to external environment influence.

1. Introduction

The construction of facial walls should be prepared to work in border condition both in humidity as well as temperature aspect. Thus the type of mortar used is significant. Some suggestions regarding mortar selection were included in Eurocode 6. It seems that this subject was covered comprehensively. However, the analysis of requirements associated with Eurocode 6 indicates that in the set of EN 771 standard there were no researches referring this subject. Mural mortars belong to a group of materials chemically active for which two kinds of corrosion can be distinguish: internal and external, [1]. The basic reason of corrosion are internal factors which include properties of built-in materials and their mutual interactions, Wesołowska [2], Henkel [3], Van Vlack [4]. Laboratory researches, led by Brocken [6], Brachaczek [5], concerning migrations of chemically active compounds indicate that solved calcium hydroxide outflows from mortar and dries undergoing carbonation. Thus essential role is played by mortar compound. External factors include mostly sulphate, sulphide and chloride solutions, but also gaseous CO_2, acid rains and changeable temperatures often exceeding zero point, [1].

Construction mortar plays important role in limiting humidity penetration into wall interior. It should constitute a barrier to rain water penetration and enable its easy exit outside in case it occurs. Thus the mortar microstructure stability is important.

2. Research methods

2.1. Field station

The field test station for research was localized in area of the University of Science and Technology in Bydgoszcz (Poland). The research station includes eight test walls one brick thick and measuring 1,61 x 1,42 m. The walls were placed with sides faced at the wind direction stated according to reports by Voivodeship Inspectorate of Environment Protection in Bydgoszcz (Poland). They were built with full clinker brick in a set with eight different mortars of which six had known material composition and two other were ready-made with indication for use in facial walls in order to avoid efflorescence (Figure 1). For purpose of this article 3 walls were chosen with mortars which composition were given in Table 1.

Table 1. Composition of mortars subjected to research.

Mortar	Component proportions	Composition of 10 dm^3				
		Cement [kg]	Lime [kg]	Sand [dm^3]	Plasticizer [g]	Water [dm^3]
CEM I	(c:p)=1:3.5	3.78 kg CEM I 42.5N	-	10.5	-	2.53
CEM I + plasticizer	(c:p)=1:3.5	3.78 kg CEM I 42.5N	-	10.5	4.0	2.33
C-L	(c:w:p) = 1:1.25:6.75	1.65 CEMI 42.5N	0.97	9.5	-	3.04

In a such designed wall anti-humidity insulation was made on two levels:

- on foundation wall (10cm under ground level),
- 50cm above the ground level.

The insulation was intended to protect against water migration from concrete foundation and select the area endangered with splash water.

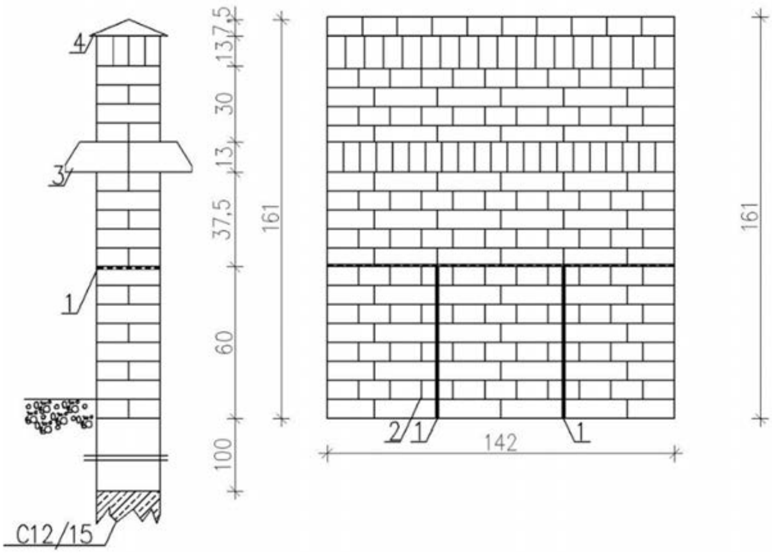

Fig. 1. Test wall for field research 1 – insulating tarpaper underlay, 2 – 1/2W fitting, 3 – 1K fitting, 4 – DD fitting.

2.2. Preparation of samples for tests

The analysis covered two groups of mortars:

- in initial state – from performed mass there were laboratory samples taken than formed into beams sized 40x40x160 mm. After 24h the samples were disbanded and then conditioned in a chamber with 60% humidity and ambient temperature of 20±20C for the next 27 days.
- functioning in walls, subjected to exposition to external climate conditions during 10 years (from each selected wall there were 6 samples of mortar taken 5mm thick; the material so obtained underwent salt extraction process through multiple rinsing and soaking).

So prepared samples were dried to solid mass.

2.3. Mercury porosimetry test

Microstructure tests were done with AutoPore IV series 9500 porosimeter equipped with two ports: low and high pressure of maximum value of 33000 psia (228MPa), which lets measuring within the range of meso- and macrospores (from 2nm do 360μm). Before the real measuring the calibration and blank test were done – to set volume, compressibility and thermal effect of penetrometer used. Basing on control measures it was defined equilibrium time of 30s. As a result of measuring of prepared samples there were defined following structure parameters: total pore volume, sample volume and its skeleton volume, pore volume distribution in function of their diameter as an integral and differential relation.
Pore volume share was calculated with a formula:

$$U_{MEZO} = \frac{\sum_{i=2nm}^{50nm} IV_{MEZO}}{TIV} \cdot P, \qquad (1)$$

$$U_{MAKRO} = \frac{\sum_{i=50nm} IV_{MAKRO}}{TIV} \cdot P \quad (2)$$

where: IV_{MAKRO} – Intrusion Volume, ml/g; IV_{MEZO} – Intrusion Volume, ml/g
TIV – Total Intrusion Volume, ml/g; P – Porosity, %.

3. Results and discussion

As a result of mercury porosimetry the basic micro-structural parameters were obtained (Table 2). Detailed results let show the distribution of pore volume in function of their diameter. Basing on relation between the differential of volume function and pore diameter, differential curve of pore distribution was obtained which let state the dominant diameters (Figure 2).

Table 2. Basic parameters of tested mortar microstructure samples.

Microstructure parameters	Initial samples			10 years of environment exposition		
	CEM I	CEM I + plasticizer	CL	CEM I	CEM I + plasticizer	CL
Total Intrusion Volume, ml/g	0.1090	0.1127	0.1226	0.078	0.0902	0.0967
Total Pore Area, m²/g	0.598	0.545	0.304	0.354	0.438	0.260
Median Pore Diameter (Volume), nm	1919.1	3701.1	2678.9	3629.8	4255.6	3601.9
Bulk Density at 0.23 psia, g/ml	1.9664	1.9686	1.9443	2.1957	2.1244	2.0903
Apparent (skeletal) Density, g/ml	2.5029	2.5297	2.5526	2.6500	2.6282	2.6199
Porosity, %	21.43	22.18	23.83	17.14	19.17	20.21

Basing on researches performed, it was stated that independently on mortar compound it was noticed lower general porosity (Table 2) by about 3-4 percentage points. As a result of 10 years of facial walls exploitation there were also changes in mortar microstructure concerning meso- and macropores (Table 3).

Table 3. Percentage shares of porosity for samples in initial state and after 10 years of exposition – average values.

Pore volume [%]	Initial samples			10 years of environment exposition		
	CEM I	CEM I + plasticizer	CL	CEM I	CEM I + plasticizer	CL
Mesopores 2-50nm	20.61	21.16	17.65	2.62	10.27	11.45
Macropores > 50nm	0.82	1.02	6.18	14.52	8.90	8.76
Total porosity	21.43	22.18	23.83	17.14	19.17	20.21

The most changes were noticed in CEM I cement mortar, where macropore share increased from 0.82% to 14.52%. The detailed analysis of integral curves indicates that increase of porosity in diameters $\geq 1 \cdot 10^5$nm occurred with creation of additional dominant diameter equal $3 \cdot 10^5$nm. The share of mesopores increased nearly by 8 times.

In cement mortar with plasticizer the volume of macropores increased from 1.02 to 8.9 %. This is due to significantly higher porosity values within the range of diameters $\geq 1 \cdot 10^3$nm. In this range two dominant diameters were created i.e. $4 \cdot 10^4$nm and $1 \cdot 10^3$nm. The mesopore share decreased two times. Cement-lime mortar occurred to be a material solution the least susceptible to long-term environment influence. The noticed changes of porosity from

6.18 to 8.76% cover the whole range of macropores. Similarly, as in cement mortars, the number of mesopores decreased, but differences were definitely lower (Figure 2).

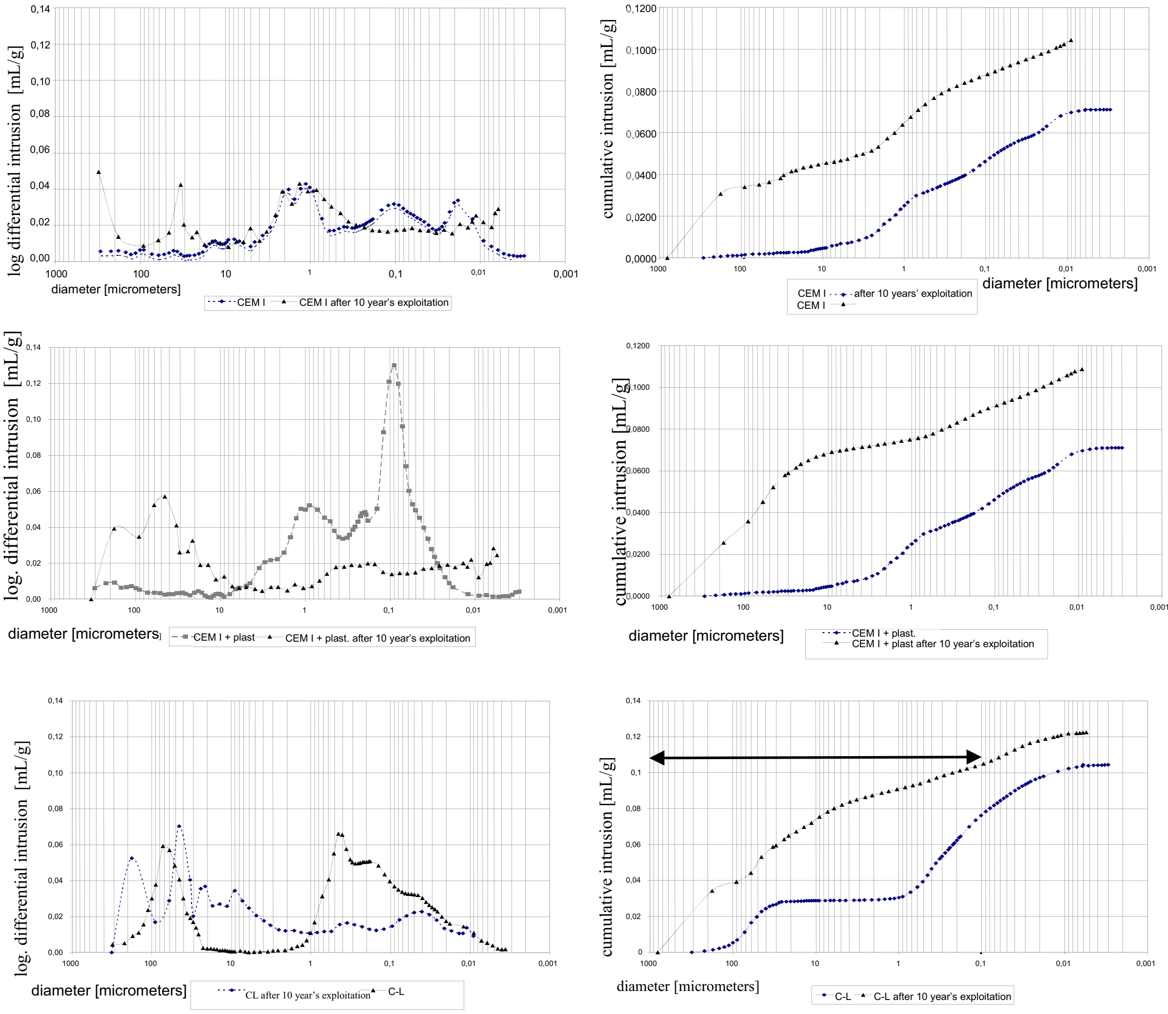

Fig. 2. Differential and cumulative intrusion of pore size distribution in the tested mortar samples.

4. Conclusions

In the article there were analyzed changes in mortars under multi-year exposition to external environment. Ten-year exploitation of a wall covered with efflorescence caused changes in microstructure of mortars. The most susceptible occurred to be the CEM I cement mortar. Additional pores of big diameters ($3\cdot10^5$nm) occurred in it which are the effect of ongoing destruction. Addition of plasticizer does not influence meaningfully the cement mortar durability. The microstructure of this mortar is characterized also by essential macropore increase. The least microstructure changes were noticed in cement-lime mortar. The mortar porosity increased slightly within the whole micropore range. The addition of lime positively influenced mortar resistance to environment impact.

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